Int J Life Cycle Assess (2010) 15:540–548
DOI 10.1007/s11367-010-0198-x

ENVIRONMENTAL PRODUCT DECLARATION

Definition of the methodology for a Sector EPD (Environmental Product Declaration): case study of the average Italian cement

Carlo Strazza · Adriana Del Borghi · Gian Andrea Blengini · Michela Gallo

Received: 8 October 2009 / Accepted: 30 April 2010 / Published online: 19 May 2010

Abstract
Purpose The objective of this paper is to describe the process of development of an appropriate methodology for a type III label that can be used by a trade association, namely “Sector Environmental Product Declaration” (EPD). The study starts from the definition of required data, data collection procedures, sample selection criteria etc. With this aim, the application of the scheme on a case study has been conducted, regarding the cement production in Italy.
Methods The methodology has been selected coherently with the requirements of the International EPD® system. The basis for the definition of the methodology of the study was the document Product Category Rules 2004:01 for the Product Group “Cement”. Since these rules were prepared before the introduction of the International EPD® system, the guidelines have been refined in order to suit the revised programme instructions, whose spectrum includes the innovative case of the Sector EPD.
Results and discussion A pre-inventory analysis, aimed to the sample selection for the case study presented, has been conducted. The elements influencing the selection of plants and products were geographical position of plants and eventual company/group affiliation, plant productivity, process technology type, fuels and raw materials use and product typology. Seven plants have been identified. The environmental impacts are referred to the production of 1 ton of representative average cement. “Representative” is referred to the selection of the panel of typical cement plants, whilst “average” refers to data source. In particular, for every selected plant, the analysis has yielded the results related to an average cement, including all the typologies there produced; then, the average profile is derived. It can be remarked that the relative contribution of the different life cycle phases remains almost unchanged for every impact category. Apart from waste production, the distribution appears rather uniform. The amount of clinker results as the main potential source of variation for the impacts, as regards the different cement typologies.
Conclusions It can be concluded that a targeted analysis of the sample representativeness is required to support the robustness of the selection in view of the successive verification process. The incoming revision of the Product Category Rules, in order to extend the application spectrum to product-type declarations, will enable the compilation of the life cycle assessment results presented in this paper in a Sector EPD for the case study.

Keywords Cement · Environmental Product Declaration · ISO 14025 · ISO 14040 · Life cycle assessment · Sector EPD · Trade association · Type III label

C. Strazza (✉) · A. Del Borghi · M. Gallo
Department of Chemical and Process Engineering, “G.B. Bonino” (DICheP), University of Genoa,
Via all’Opera Pia 15,
16145 Genova, Italy
e-mail: carlo.strazza@unige.it

A. Del Borghi
e-mail: adriana.delborghi@unige.it

M. Gallo
e-mail: michela.gallo@unige.it

G. A. Blengini
Department of Production Systems and Business Economics, DISPEA, Politecnico di Torino,
C.so Duca degli Abruzzi 24,
10129 Turin, Italy
e-mail: blengini@polito.it

1 Introduction

The demand for a better environmental quality is presently one of the key issues influencing the behaviour and the market choices of larger and larger groups of individuals, which are increasingly paying attention to the environmental performance of products.

This represents a new and promising green market outlet for firms that are trying to understand and satisfy the environmental expectations of their customers, including those in the sectors of building materials.

The building sector, in fact, including housing, has a strong weight on the society's total energy demand and total material use; therefore, it has to be prioritised in a sustainability direction (Erlandsson and Borg 2003).

From the firm point of view, a typical problem which has to be faced by those producers actively engaged in environmental sustainability issues is to identify and capture the competitive advantage arising from their responsible environmental behaviour. However, in order to address market competition towards eco-responsible targets, it is necessary to adopt instruments which allow comparison of products based on scientifically sound, objective and comparable indicators.

Moreover, it has widely been recognised that the environmental consequences of production are well extended beyond the physical boundaries of the production sites, the whole life cycle of products being a potential source of environmental impacts to be understood and kept under control (Badino and Baldo 1998).

For instance, the assessment of the environmental performances of building products cannot be limited to a single step in the production chain. It must be recognised that every single process in the production chain is inseparably connected with the other upstream or downstream activities. In particular, there is evidence that it is the need for and the subsequent use of building materials the very reason for which a production activity exists (Badino et al. 2006). In other words, demand for these products is derived rather than direct, and so it makes sense to consider their environmental performance within the context of their intended use as well as during production.

Thus, when assessing the environmental impact of a building product, the evaluation has to be extended throughout all the life cycle. It would be nonsense to limit the analysis to a single step, whereas not only the environmental characteristics of each phase are interconnected but also the environmental consequences of quarrying and manufacturing can be even lower than the ones in the downstream sectors (Badino et al. 2006).

This expanded view is consistent with the shift towards green supply chain management: The producer of the final product strives to ensure that the components used are produced sustainably. It is also consistent with the UN Agenda 21's goals of sustainable construction, which is a holistic way of thinking about buildings that encourages harmony between the natural and built environment (Du Plessis 2001). Construction materials should be produced in a sustainable manner, and design should be environmentally oriented.

Another key issue is the protection of the local and European Union markets against the unfair competition by those producers that can supply low price raw materials but with much higher environmental burdens (Badino et al 2003). This occurs because in the absence of government actions (taxes, fees, environmental regulation etc.) forcing firms to internalise the environmental costs of their activities, only responsible firms will do so. But they must compete with firms that can price their products lower because they do not face the same set of costs. To do so effectively, they need information that clarifies the relative value of their products.

For these reasons, the life cycle assessment (LCA) methodology is increasingly being used as an objective and credible tool to measure the environmental performances of products and understand the environmental sustainability of the production chain.

In such a context, it becomes topical to enable the markets' understanding and taking into account of the environmental background of products. This is the field of environmental labelling, aimed at communicating to the potential intermediate or end customers that producers do care about the internalisation of environmental externalities that are caused by their products.

1.1 Environmental Product Declaration: the EPD® system

Systems for type III Environmental Product Declarations (EPDs) are gradually becoming more known and operational on the market. EPD is a communication tool that provides environmental data on products and services using predetermined parameters and, where relevant, additional environmental information. The so-called EPD® system (www.environdec.com) is one of these programmes operating on the market in several countries, which has considerably gained importance during the last decade.

This type of formalised product declaration relies on life cycle analyses according to ISO14040 series (ISO 2006a; Klöpffer 2005). This environmental management tool evaluates the effects of a product on the environment over the entire period of its life: from the extraction and processing of the raw materials through the manufacturing, packaging and delivery processes, the use, re-use and maintenance of the product and onto its final recycling or disposal as waste at the end of its useful life. Through the assessment of emissions and consumption of resources at every stage of the life cycle, the environmental impacts

from the entire life cycle of products and services are addressed.

The ISO standard for EPD, i.e. ISO 14025 (ISO 2006b), published in 2006, describes the procedure necessary for preparing the declarations, how to develop consistent and comparable data sets (Grahl and Schmincke 2007; Schmincke and Grahl 2006), according to common rules, i.e. Product Category Rules (PCR; Fet and Skaar 2006).

The publication of ISO 14025 and the experience gained from an EU project entitled "Requirements for an international EPD scheme" (INTEND project 2005) have recently called for a revision of the EPD® system. The revision work has, to a large extent, been focussed on a further broadening of the scheme to a system with international applicability—the result being the so-called International EPD® system, meant to provide a tool for relevant and credible product-related environmental information.

The re-arrangement of the EPD organisation with the launch of the International EPD® system has led to a wide change in the EPD distribution by countries and sectors, mainly owning to the new classification scheme for products categories based on Central Product Classification scheme used for structuring PCRs into a hierarchic level based on a modular approach (Del Borghi and Gallo 2008). Nevertheless, so far, the registered EPDs have been tailored in order to inform about the environmental performance of specific goods and services. Many industrial associations instead show growing interest on "product-type EPDs", in contrast to product specific EPDs.

The objective of this paper is to study the development of a new feature of the International EPD® system, i.e. the Sector EPD. This tool shows a sort of average environmental profile of the product, based on the typical processing adopted in the local context and representative of the production offered by the sector.

This declaration can find application in the use as representative average for a well-defined geographical area for the upstream and manufacturing processes in the search and development of more product-specific PCR documents. Besides, a sector EPD can be used as a sector benchmark for separate producers manufacturing or offering products and services in the same product category. In addition, it can also be used as a guidance tool indicating the general environmental performance of a product category, i.e. for planners, designers and architects in the construction sector not needing information from specific products from selected suppliers, according to the reference document "Introduction, Intended Uses and Key Programme Elements for Environmental Product Declarations, EPD" (2008).

Since the EPD is a concise document that outlines a simple profile of the environmental performances of a product, including objective, comparable and credible data, the definition of an appropriate methodology must be performed with particular rigour. This paper aims to describe the process of development of this methodology, starting from the definition of required data, data collection procedures, sample selection criteria etc. The application of the scheme on a case study has been conducted, regarding the cement production in Italy.

The choice of a building material as a case study is also supported by the activity of the European Commission as concerns the integrated policy product voluntary approach (European Commission 2003) that assesses products within the construction sector by focusing on the whole product life cycle.

The inter-universitary Centre for the Development of Products Sustainability (CE.Si.S.P., University of Genoa, Italy) has performed the complete related LCA study (Del Borghi and Strazza 2008), which has undergone an independent review and whose main results are presented in this paper.

2 Materials and methods

2.1 Environmental aspects of cement industry

Cement is a powdered substance mainly used as binding agent in concrete production. It is produced through several stages, basically made up of the two following essential phases:

- Manufacture of a semi-finished product, so-called clinker, obtained from the calcination in a high-temperature kiln of a "raw mix" made up of a mixture of clay, limestone and several other additives
- Manufacture of cement as a finished product, obtained by the homogeneous mixture of the ground clinker and calcium sulphate (gypsum) with or without—depending on the type of cement—one or more additional components: slag, fly ash, pozzolana, limestone etc.

The core technology of the cement plant is the kiln and the ancillary equipment where calcining takes place at 800–900°C and breaks the calcium carbonate down into calcium oxide and carbon dioxide, which is released. Clinkering completes the calcination stage and melts the calcined raw mix into hard nodules resembling small grey pebbles. Material temperature in the burning zone of the kiln ranges from 1,350–1,450°C (main flame up to 2,000°C); this is the area where capital costs are highest, fuel demands are largest and process control is the most crucial. Kiln technology varies from vertical shaft to long rotary kilns, to Lepol kilns, to suspension pre-heater with pre-calciner kilns. One of the possible differences amongst these technologies can be the specific heat consumption.

The high temperatures required for raw mix burning mean that the process is "energy intensive". Electrical

energy is required for raw milling and mixing, burning and finish milling, but the largest energy demand must be ascribed to the fuel needed for burning the raw mix.

Finish milling entails the grinding of clinker in order to produce a fine grey powder. Gypsum ($CaSO_4$) is ground together with the clinker, along with other materials, in order to produce finished cement. Gypsum is responsible for the control of cement hydration rate in the process of cement setting.

The environmental aspects of the cement industry are closely connected to the air emissions, i.e. generally dust, that have many sources throughout the cement processing, carbon dioxide, nitrogen oxides and low amounts of sulphur dioxide, mainly from the kiln. On the other hand, the cement industry is able to use alternative fuels and raw materials to reinforce its competitiveness and at the same time contribute to solutions to some of society's waste problems in a way which valorises the waste and is beneficial to the environment. For instance, on condition that particular attention is paid about metals concentrations in clinker, the recycle of cement kiln dust, created during the third stage of manufacturing when clinker is formed, reduces the need for limestone and other raw materials and contributes to energy saving.

In general, the recent environmental policies led the cement industry to adopt some typical abatement activities such as:

- Increased use of mineral addition and supplementary cementitious material in order to reduce the clinker content in cement, the result being an effective reduction of the chemical process emissions
- Increased utilisation of alternative raw materials and fuels
- Improved energy efficiency through modern kiln technologies

2.2 Life cycle assessment of cement production for a Sector EPD

In order to conduct a life cycle assessment study with the aim of developing an Environmental Product Declaration, precise methodological choices are required, whose definition must consider the comparability amongst different studies. Therefore, common and harmonised calculation rules have been adopted since similar procedures must be used for data collection and handling. This applies, for instance, to goal and scope of the study, upstream and downstream system boundaries, assumptions done as well as the choice of calculation methods.

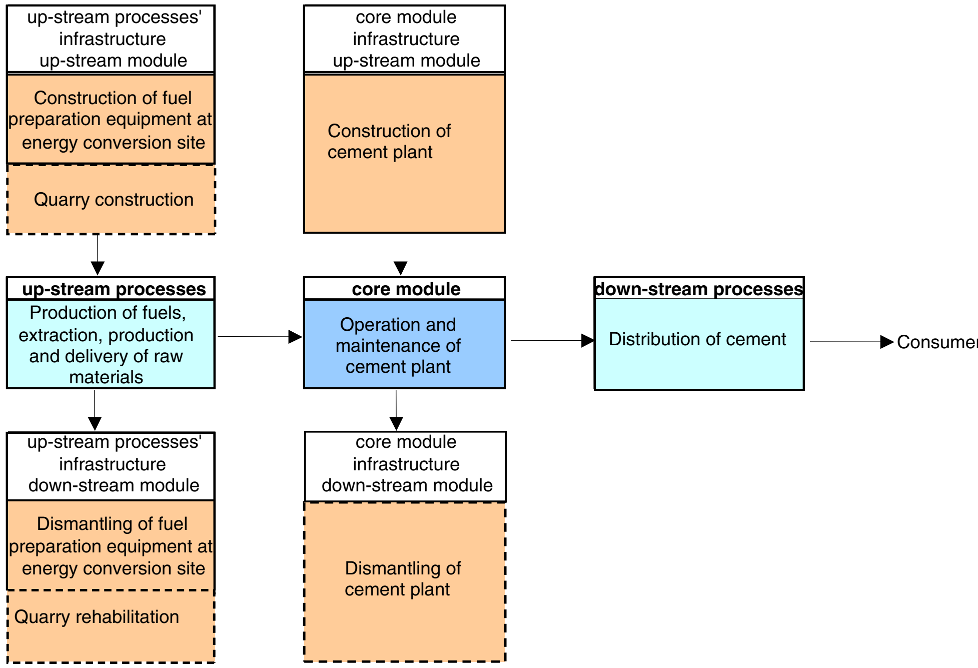
The methodology used in this study has been thereby selected coherently with the requirements of the EPDs as defined in the document "General Programme Instructions for Environmental Product Declarations, EPD" (2008). The basis for the definition of the methodology of the study was the document PCR 2004:01 (2004). This document describes the scope and goal of the LCA for the development of an EPD, as it sets the parameters for the assessment of the environmental performance for the Product Group "Cement". Since these rules were prepared before the introduction of the International EPD® system, the guidelines have been refined in order to suit the revised programme instructions, whose spectrum includes the innovative case of the Sector EPD.

The functional unit has been defined as 1 ton of cement produced. Besides, the selection of system boundaries, represented in Fig. 1, reflects the goal of the production process, as a general rule. The upstream processes cover fuels and raw materials production (including transports towards plants), mining operations, as well as construction and dismantling of fuel production plants; quarry construction and rehabilitation have been evaluated as optional stages, and not considered in this study. The core module covers the following lifecycle phases: plant operation (i.e. clinker production and cement production) and plant construction, whilst its dismantling is considered as optional and excluded from this study. Cement distribution would represent the downstream process, but it is considered to stay out of the selected boundaries in order to guarantee the maximum homogeneity between the different existing cases in the panorama of the country. Moreover, this modular procedure is highly coherent with the modularity approach promoted by the International EPD® system.

Since the cement production process entails the use of alternative raw materials/fuels, some considerations have to be highlighted as concerns the allocation rules regarding these materials. In this study, the approach referred to as the "polluter-pays allocation method" has been applied, as stated in the reference document "Supporting Annexes for Environmental Product Declarations, EPD" (2008). According to this approach, the user of the waste has to carry the environmental impact from the processing and refinement of the waste, but not the environmental impact caused in the "earlier" life cycles. In particular, a waste flow from a supplier that can be used without affecting the waste generator's process is free of environmental burden for the user. The further processing of materials subject to recycling are allocated to the next product system which utilises the recycled materials as material input, such as the collection process.

Life cycle inventory work has identified different forms of resources use and pollutants emissions that usually have different potential environmental impacts within the so-called impact categories. The potential environmental impacts are calculated using characterisation methods that make it possible to associate the scale of a pollutant emission to selected so-called characterisation/conversion

Fig. 1 The system boundaries



factors. For this study, a method coherent with the EPD requirements has been selected, following the principles inserted in the document "Supporting Annexes for Environmental Product Declarations, EPD" (2008). Therefore, in this work, the potential environmental impacts associated with the various types of use of resources and pollutant emissions have been reported into the following impact categories: emission of greenhouse gases (expressed as the sum of global warming potential (GWP), 100 years, in kilograms of CO_2 equivalents), emission of ozone-depleting gases (expressed as the sum of ozone-depleting potential in kilograms of CFC 11-equivalents, 20 years), emission of acidifying gases (expressed as the sum of acidifying potential (AP) in kilograms of SO_2 equivalents), emission of gases that contribute to the creation of ground-level ozone (expressed as the sum of ozone-creating potential (POCP) in kilograms of C_2H_4 equivalents) and emission of substances to water contributing to oxygen depletion (expressed as the sum of oxygen consumption potential (EP) in kilograms of PO_4^{3-} equivalents). This study has included two categories that reflect the use of non-renewable/renewable resources with energy content, expressed in megajoule equivalents (by means of gross calorific values), and two categories that reflect the use of non-renewable/renewable resources without energy content, expressed in kilograms. In addition, the analysis has included water consumption (kilograms), waste production (kilograms) and, finally, direct dust emissions. In this paper, the most significant parameters explored are presented.

The LCA study for the calculation of the environmental impacts to be inserted in the declaration has been carried out with the help of the LCA software tool SimaPro 7.1, developed by PRé Consultants (2008).

All data are referred to the reference year 2006.

In the preparation of a Sector EPD, it must also be considered that the relative verification procedures may have to be somewhat stricter compared to company-specific EPDs. In particular, in the General Programme Instructions (2008), it is stated that it is important to evaluate if there exist clear differences amongst the sites.

The methodology must therefore entail appropriate considerations regarding representativeness and relevance. From the analysis carried out, it emerges that the elements influencing the selection of plants and products to be included in the study are:

- Geographical position of plants and eventual company/group affiliation
- Plant productivity
- Process technology type
- Fuels and raw materials use
- Product typology

Besides, in the development in the methodology, all sections referring to product-specific details are replaced with the same type of information as average values for the sector under study. As resulted from the analysis, it is recommended to assess the consistency of the following aspects:

- The product description may only refer to the general framework for using the product with limited information on technical specifications

- The calculation rules referring to specific data may be neglected
- The recommended use of generic data for a specific material supplementing a product-specific PCR document may preferably be replaced with average values representing all the manufacturing sites for that specific material and the region under study, as appropriate
- Selected environmental impact categories may be omitted if having a more restricted regional relevance compared to the overall regional coverage of the Sector EPD

With regards to the cement production in Italy, the definition of the required data and data collection procedures for the inventory phase of the LCA study has been based on the following particular considerations:

- Data concerning clinker and cement composition, as well as data for energy consumption, must be provided by the producers
- Data concerning infrastructure can derive from selected database, with reference to the specific production volume for every plant
- Data concerning road transports for raw materials and fuels, atmospheric emissions (including dust) can be referred to clinker, firstly, and then normalised for the functional unit

3 Results and discussion

The first part of the study has regarded the pre-inventory analysis aimed to the sample selection for the case study presented in terms of representativeness. A preliminary technological screening has identified seven plants homogenously dislocated in the Italian territory.

In the selected plants, the kiln with multi-stage pre-heating and pre-calcination is the predominant technology. This reflects not only the Italian subdivision, representing about half of the Italian kilns and half of the sample kilns, but also the indications on the best available techniques. In fact, the reference document for cement deriving from the Integrated Pollution Prevention and Control activities of the European Community (European Commission 2000) asserts that, for new plants and major upgrades, a dry process kiln with multi-stage pre-heating and pre-calcination is the best solution. For the analysis, this kiln that is actually the most present in Italy and Europe is considered to be fed both with fossil fuels and with alternative fuels.

It has been then assessed that the sample presents a production spectrum (Fig. 2) that is congruent with the cement typologies production distribution in the country (AITEC 2007). Besides, owning to the marked prevalence of CEM II production with respect to all the other

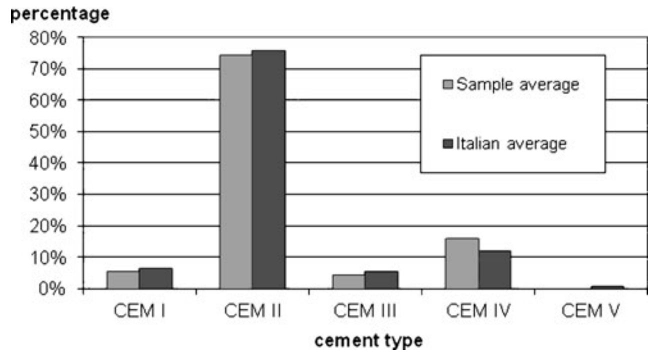


Fig. 2 Cement typologies production for the selected sample

typologies, it is worth delving into the particular analysis about this product branch, as a deepening study, although in this paper the environmental results are presented for the average cement only, as illustrative example.

With regards to the plants productivity, the total cement production in the selected plants results to be equal to 13% of the national production.

The analysis has been finally focussed on energy consumptions. Table 1 shows the energetic data of the selected plants, compared to the values of the average Italian performance (AITEC 2007).

Once evaluated the representativeness of the sample, the environmental results of the case study to be included in the Sector EPD are here presented.

The environmental impacts highlighted in order to compile the information requested by the declaration are reported in Table 2. The results are therefore referred to the production of 1 ton of representative average cement, where "representative" is referred to the selection of the panel of typical cement plants applying the most representative dry process technology and cement types, raw materials and fuels, whilst "average" refers to data source, in fact average data, are derived from real industry data. In particular, for every selected plant, the analysis has yielded the results related to an average cement that includes all the typologies there produced; then, the average profile is derived from the average values of the plants constituting the sample.

The relevant gas emissions related to global warming in the life cycle inventory compiled in this study are constituted by carbon dioxide (CO_2) direct emissions from the kiln. In the analysis of the substantial quantitative effect of CO_2 emissions, these data are in accordance with what stated by the Intergovernmental Panel on Climatic Change (Houghton et al. 1996) that sees the production of cement as a relevant industrial source of CO_2 emissions. The homogeneity of the estimation procedures is guaranteed by the compliance of the monitoring and reporting guidelines of the EU Emissions Trading Scheme (EU 2003) and with the flexible tool for accounting and reporting CO_2 emissions developed under the umbrella of the Cement

Table 1 Energy consumptions for the selected sample (all data are referred to 1 ton of cement produced)

	Electricity (kWh)	Natural gas (m^3)	Coal (t)	Heavy fuel oil (t)	Non-conventional fuels (t)
Sample average	115	0.88	0.068	1.19×10^{-3}	4.81×10^{-3}
Italian average	109	0.87	0.063	2.32×10^{-3}	3.72×10^{-3}

Sustainability Initiative of the World Business Council for Sustainable Development, i.e. the WBCSD Cement CO_2 Protocol (2005).

From the analysis of the data collected, global warming potential category exhibits a rather uniform distribution, where the most significant contributions come from the plants that show the major impacts also for ozone depletion potential and consumption of non-renewable resources without energy content. This relationship is clearly visible in Fig. 3, in which the environmental impacts for the average cement produced in the seven plants constituting the sample are compared.

Apart from waste production that seems more specifically linked to the plant characteristics, it can be deduced that, globally for every category, the distribution appears rather uniform. In the survey, it has been observed that the plant showing impacts standing notably out against the average, as concerns photochemical oxidation and, above all, acidification and eutrophication potentials, finds the main reason in the contribution of the direct emissions from the kiln. In particular, it seems that Lepol kiln typology has a strong negative influence on the atmospheric emissions. This effect is directly transferred from clinker production stage to cement production stage and then maintained for every typology, including CEM II. The notable variation in certain categories between a single plant and the rest of the sample therefore finds its justification in the process technology.

Moreover, in all the plants constituting the sample, it can be remarked that the relative contribution of the different phases of the life cycle remains almost unchanged for every impact category. In particular, direct emissions from the plants present a significant contribution for GWP (more than 80% for clinker production stage), EP (more than 50%), AP (more than 40%) and POCP (more than 10%).

The impact deriving from clinker production stage is highly predominant in the core module, for every plant and consequently for the average profile. This contribution is seen to be slightly mitigated in the category related to raw materials use, but the specific contribution related to the further processing is found in the consumption of renewable resources with energy content, mainly owning to the energy use necessary for clinker and additives grinding phase.

In Fig. 4, the characterisation of a single plant from the sample selected is reported as an illustrative example. All the plants in fact show clinker contribution as the prevalent impact share for every impact category.

The main potential source of variation in the results, as regards the different cement typologies, is the amount of clinker. It also emerged the environmental burdens for CEM II production do not significantly differ from those relative to the average cement.

4 Conclusions

The present paper shows the application of LCA for the development of a Sector EPD, through the analysis of a

Table 2 Environmental impacts and resource consumptions (all data are referred to 1 ton)

Impact category		Cement	Standard deviation
Global warming (GWP100)	kg CO_2	769.34	74.05
ODP	kg CFC-11	4.95×10^{-5}	8.34×10^{-6}
POCP	kg C_2H_4	0.15	0.03
AP	kg SO_2	2.05	1.00
EP	kg PO_4^-	0.33	0.18
Non-renewable resources, with energy content	MJ	6.17×10^{3}	1.03×10^{3}
Renewable resources, with energy content	MJ	108.35	217.67
Non-renewable resources, without energy content	kg	1.36×10^{3}	1.20×10^{2}
Renewable resources, without energy content	kg	95.25	73.21
Water consumption	kg	4.82×10^{3}	1.41×10^{3}
Waste production	kg	1.07	0.67
Dust production	kg	0.03	0.03

ODP ozone layer depletion, *POCP* photochemical oxidation, *AP* acidification, *EP* eutrophication

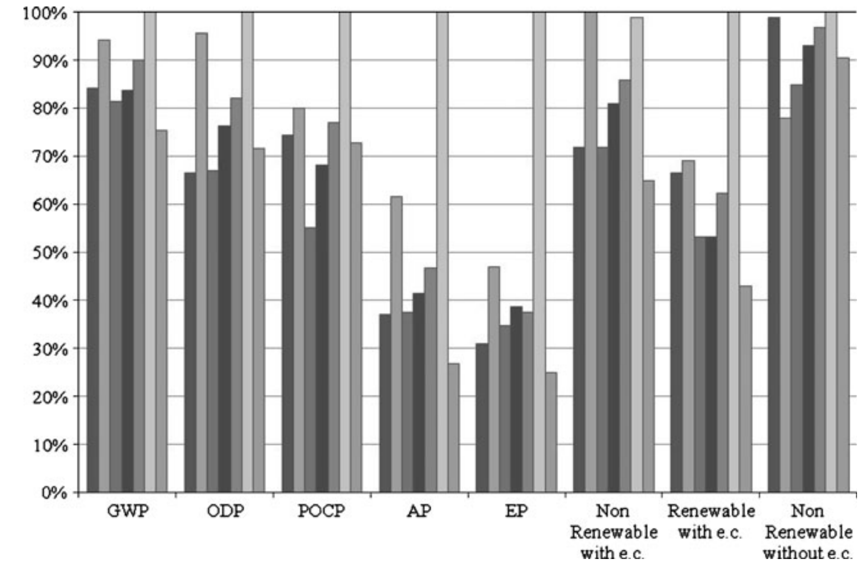


Fig. 3 Characterisation of the cement production process—comparison of the seven plants selected

case study, i.e. the production of cement in Italy. The intent of the research is to provide an example of formulation of a methodological approach for the redaction of an Environmental Product Declaration providing an average environmental profile.

The research highlights that a targeted analysis of the sample representativeness is required to support the robustness of the selection in view of the successive verification process. At the same time, some methodological choices have to be established in order to define the procedural criteria on the base of the transition from a product-specific to a product-type declaration, as regards product description, calculation rules, data quality, impact categories etc.

The LCA results presented in this paper could be published in a Sector EPD for the case study, once the revision process of the Product Category Rules, in order to extend the application spectrum to product-type declarations, is completed.

In particular, the analysis of environmental results indicates clinker production stage as the main driver for the potential environmental impacts. Moreover, it can be concluded that the environmental profile is based on a homogeneous data distribution; global warming category particularly shows a uniform profile, demonstrating a high homogeneity of the sector production in the country.

In conclusion, the life cycle approach applied to the Italian average production of cement shows that LCA represents an environmental management tool able to communicate environmental information by the type III environmental label EPD, i.e. the Sector EPD recently introduced by the International EPD® system, following common rules targeted for a product-type declaration.

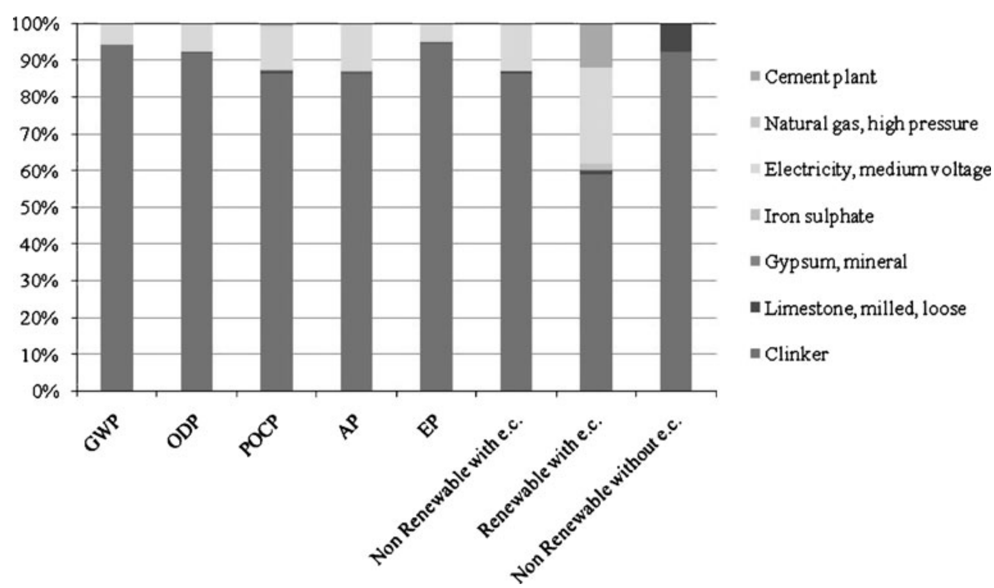


Fig. 4 Environmental impacts and resource consumptions of a single plant

References

AITEC (2007) 2006 annual report. Italian Cement Engineering and Economic Association, Rome. http://web.aitecweb.com/AREA%20ECONOMICA/RELAZIONE/annual2006.PDF

Badino V, Baldo GL (1998) LCA, Istruzioni per l'Uso. Esculapio Editore, Bologna

Badino V, Blengini GA, Dinis Da Gama C (2003) Sustainable Development Indicators as a tool for monitoring unfair international market competition of mineral commodities. Proceedings of Conf. SDIMI 2003, Milos, Greece, pp 211–216

Badino V, Blengini, GA, Zavaglia K (2006) The contribution of the extractive activity to the life cycle impacts of buildings. Proceedings of Conf. MPES2006, Torino, Italy, pp 759–764

Del Borghi A, Gallo M (2008) EPD Statistics: the effect of the launch of the international EPD® system. EPD® newsletter, No. 3

Del Borghi A, Strazza C (2008) Life cycle assessment of cement production in Italy. Internal report, CE.Si.S.P.—University of Genoa, Italy

Du Plessis C (2001) Agenda 21 for sustainable construction in developing countries. CSIR Boutek, Pretoria

Erlandsson M, Borg M (2003) Generic LCA—methodology applicable for buildings, constructions and operation services—today practice and development needs. Build Environ 38:919–938

EU (2003) Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. Official Journal of the European Union L275, 32–46

European Commission, Directorate-General JRC, Institute for Prospective Technological Studies, Technologies for Sustainable Development, European IPPC Bureau (2000) Integrated Pollution Prevention and Control (IPPC) reference document on best available techniques in the cement and lime manufacturing industries. European Commission, Seville

European Commission (2003) Identifying products with the greatest potential for environmental improvement. http://ec.europa.eu/environment/ipp/identifying.htm

Fet AM, Skaar C (2006) Eco-labeling, product category rules and certification procedures based on ISO 14025 requirements. Int J Life Cycle Assess 11(1):49–54

General Programme Instructions for Environmental Product Declarations, EPD (2008) http://www.environdec.com/documents/pdf/EPD_instructions_080229.pdf

Grahl B, Schmincke E (2007) The part of LCA in ISO type III environmental declarations. Int J Life Cycle Assess, Spec Issue 12(1):38–45

Houghton JT, Meira Filho LG, Lim B, Treanton K, Mamaty I, Bonduki Y, Griggs DJ, Callander BA (1996) Revised IPCC Guidelines for National Greenhouse Gas Inventories—reporting instructions, volume 1, IPPCC/OECD/IEA, Intergovernmental Panel on Climate Change. UK Meteorological Office, Bracknell

Introduction, Intended Uses and Key Programme Elements for Environmental Product Declarations, EPD (2008) http://www.environdec.com/documents/pdf/EPD_introduction_080229.pdf

ISO (2006a) Environmental management, life cycle assessment, European Standard EN ISO14040–14044. International Organization for Standardization, Geneva

ISO (2006b) Environmental labels and declarations, type III environmental declarations, principles and procedures, European Standard ISO 14025. International Organization for Standardization, Geneva

Klöpffer W (2005) Life cycle assessment in the mirror of Int J LCA. Int J Life Cycle Assess 10(6):379–380

PCR 2004:01 Product-Category Rules for preparing an environmental product declaration (EPD) for Product Group "Cement". http://www.environdec.com/pcr/pcr0401e.pdf

PRé Consultants (2008) SimaPro 7.1.5. http://www.pre.nl

Requirements for an International EPD Scheme, INTEND Project (2005) http://www.intendproject.net

Schmincke E, Grahl B (2006) Umwelteigenschaften von Produkten. Die Rolle der Ökobilanz in ISO Typ III Umweltdeklarationen. Umweltwiss Schadst Forsch 18(3):185–192

Supporting Annexes for Environmental Product Declarations, EPD (2008) http://www.environdec.com/documents/pdf/EPD_annexes_080229.pdf

WBCSD (2005) The cement CO_2 protocol. World Business Council for Sustainable Development, Geneva